# On the Possibility to Use Energy Harvesting on Beta Radiation in Nuclear Environments

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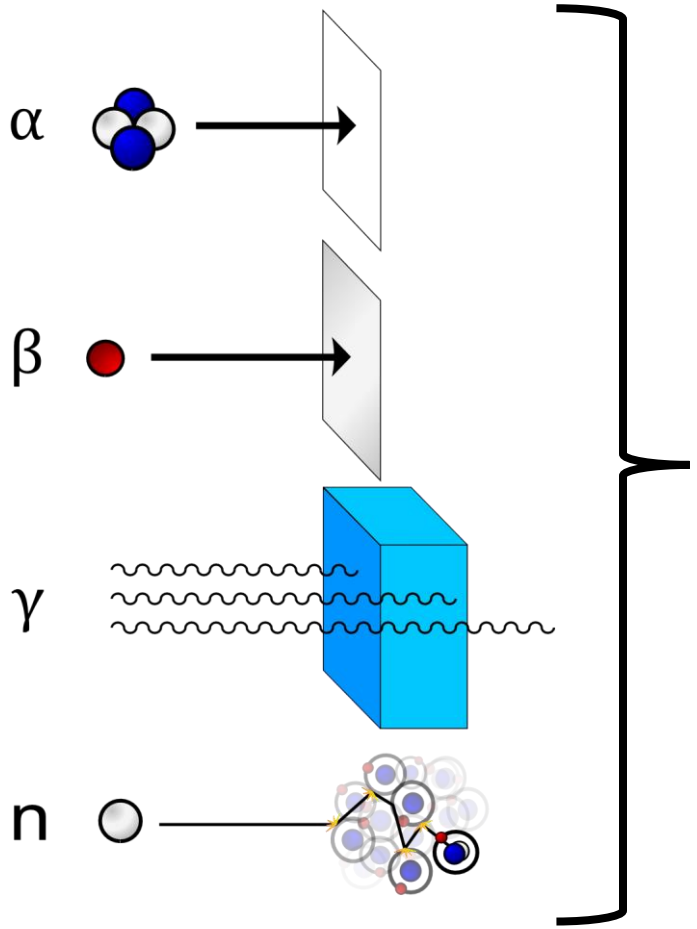
Thanks to fnrs for their support.

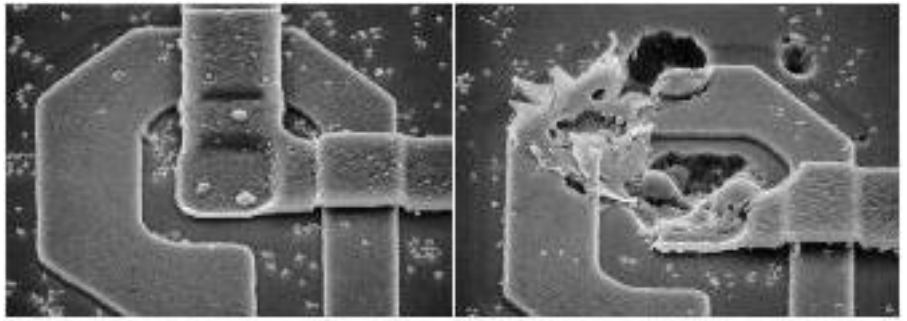
# Sensors used to monitor nuclear environments should be autonomous


- Monitoring requires sensors
- Sensors require maintenance
- Radioprotection oversees nuclear operations: As Low As Reasonably Achievable
- The best solution is to make the sensors autonomous

# We investigated the feasibility to harvest ionizing radiation to power sensors

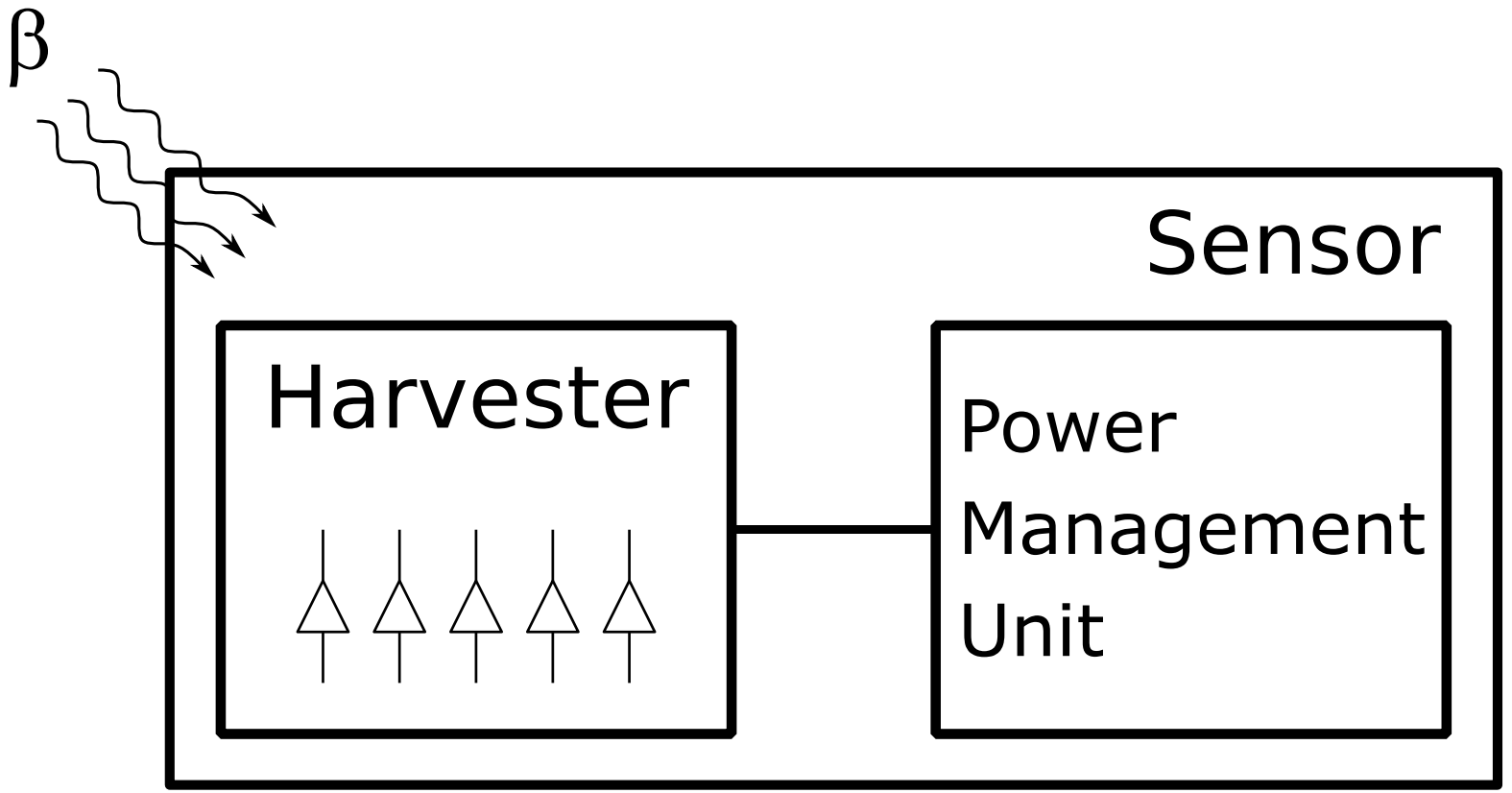



Damage!



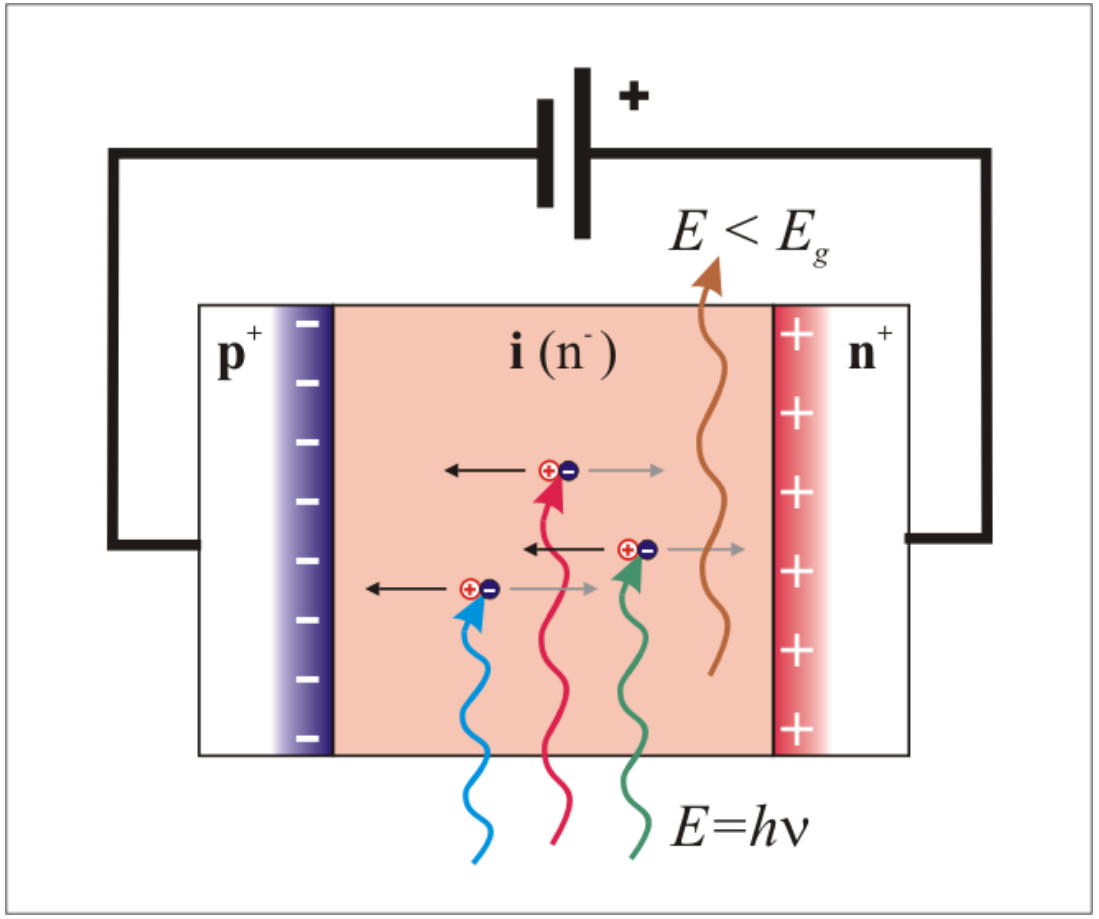
Harvesting?

# Arrays of photodiodes can be used to harvest energy from β radiation



- Experimenting beta rays harvesting
- Explaining the physics behind harvesting
- Enabling the measurements of beta currents

# PIN photodiodes are good candidates as possible harvesters for ionizing radiation

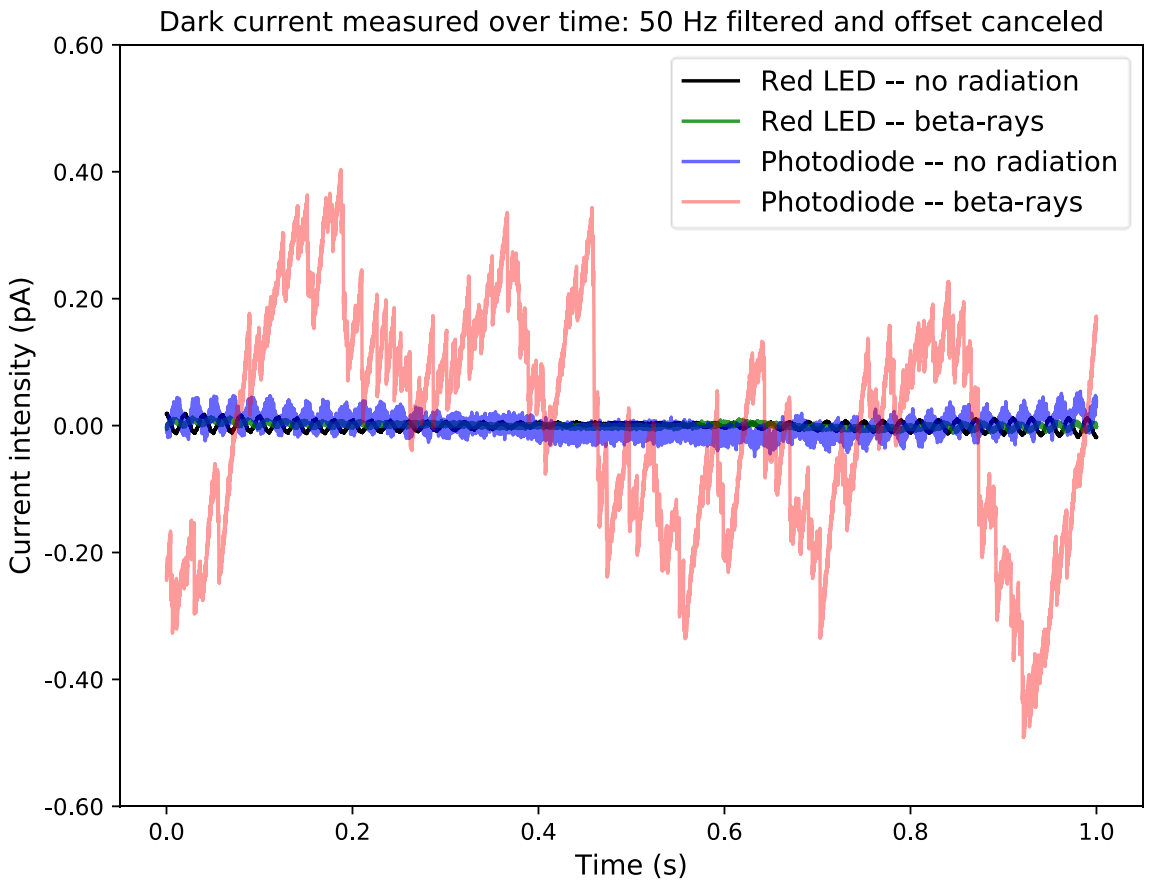



- Currently used for gamma detection, also by amateurs
- Advantages
  - Available on the market
  - Low-cost
  - Wide depletion zone

# For energy harvesting considerations, no external bias voltage should be applied

- At start-up ($t_0$), there is no energy to power the sensor
- If an external bias is required, two solutions can be investigated
  - Using a battery, but this would require maintenance (ALARA)
  - "Building" the bias voltage at $t_0$, possibly by harvesting another energy source, hence a long start-up time.
- Therefore, PIN photodiode without external bias have been investigated

# β-rays hitting a non-biased BPW34 photodiode generate a measurable current




- Increase in current
  - BPW 34 : + 12. 084 pA DC
    + 0.802 pA AC
  - Red LED : + 0.085 pA DC
    + 0.036 pA AC
- The β-ray source is a $^{90}Sr$
  - Energy up to 2.238 MeV
  - Around 1500 count/s

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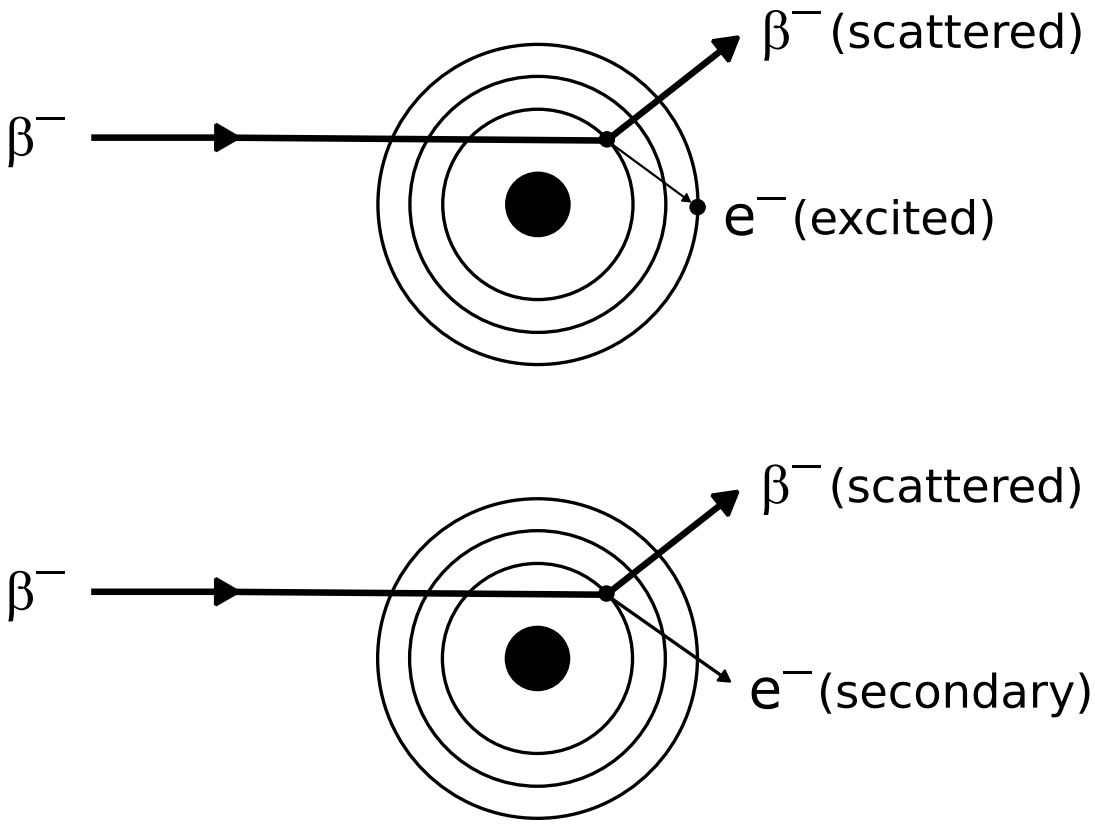
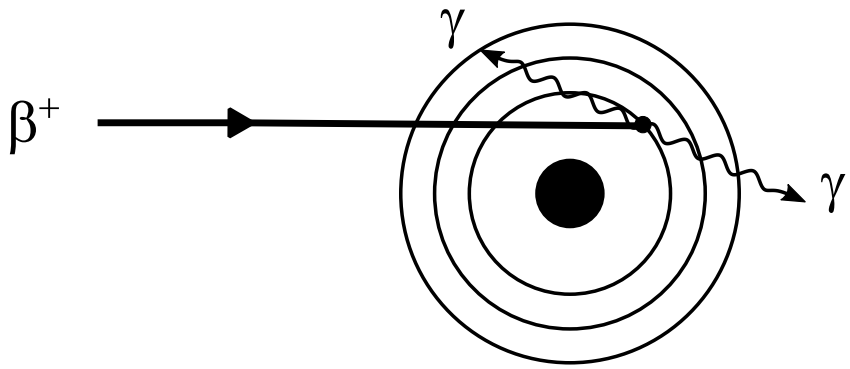
# Beta rays going through matter interact by transferring their energy



# In a semiconductor, excitation and ionization result in the creation of electron-hole pairs

- The creation of charge carriers is described by the continuity equation

$$\frac{\partial n}{\partial t} = \frac{1}{e}\nabla \cdot \overrightarrow{J_e} + G_e - U_e$$

- This generally results in undesired effects
  - Accumulation (Total Ionizing Dose)
  - Transients (Single-Event Effects)

# The main challenge is collecting the electric charges before recombination

- Two solutions can be used to complete the challenge
  - Apply a high bias voltage (like for detection) but this has been ruled out
  - Use a diode with a large depletion region and a high intrinsic electric field
- The second solution explains why PIN photodiodes are suitable as beta radiation harvesters

- Experimenting beta rays harvesting
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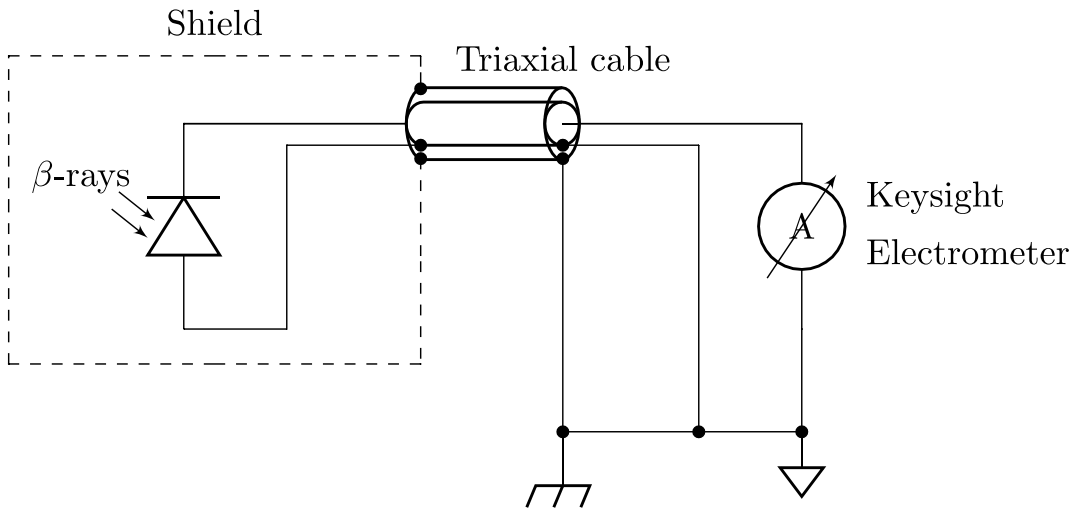
# A sufficiently sensitive measurement device is required, together with proper shielding




- Measurement's considerations
  - Device sensitivity
  - Noise reduction
- Radioprotection (safety)
  - Remote control
  - Lead wall

# The beta radiation current must be “extracted” from any other phenomenon that can occur

- PIN photodiode are photosensitive devices
  - The photoelectric effect (visible light) must be prevented
  - The device under test must be kept in the dark
- Influence from electrical grid (50 Hz in Europe)
  - Protection is guaranteed by shielding (triaxial cable, Faraday cage)
  - Digital filtering is used to remove the remaining noise

# Three facts to remember from this presentation

- Sensors can be powered by harvesting energy from β-rays
- This is possible as $\beta^-$ radiation interact with semiconductor devices, creating electron-hole pairs that can be collected
- PIN photodiodes have a wide depletion zone and high intrinsic electric field, hence the harvesting without external bias

# There is now a new type of energy that can be harvested to power autonomous sensors

- Harvesting ionizing radiation is particularly useful for nuclear applications
- It is feasible by using low-cost components available in the market
- It opens a new area of applied research

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# Sources for images and pictures

- Slide 2
  - Unknown author, “Nuclear emergency”, https://kenanmalik.com/2015/07/30/the-irrational-fear-of-radiation/.
- Slide 3
  - [Left] Wikimedia Commons contributors, “Alpha, beta, gamma, neutron radiation”, https://commons.wikimedia.org/w/index.php?title=File:Alfa_beta_gamma_neutron_radiation.svg&oldid=442494473.
  - [Top-right] ScanTech Technical Consulting, “Scanning Electron Micrograph showing before and after effects of ESD”, http://www.scantech7.com/esd-electrostatic-discharge-testing-sensitive-equipment-electronics/.
  - [Bottom-right] Hassan M., “Electricity Power Bank”, https://pixabay.com/illustrations/electricity-power-power-bank-2314633/.
- Slide 6
  - Wikimedia Commons contributors, “PIN Photodiode”, https://commons.wikimedia.org/w/index.php?title=File:Pin-Photodiode.png&oldid=427369290.